



# MSTV

MODELING AND SIMULATION, TESTING AND VALIDATION



Michigan Chapter  
**NDIA**  
National Defense Industrial Association

## UTILIZATION OF FAST RUNNING MODELS IN BURIED BLAST SIMULATIONS OF GROUND VEHICLES FOR SIGNIFICANT COMPUTATIONAL EFFICIENCY

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UNCLASSIFIED: Distribution A. Approved for public release

7 August 2013

**GVSETS**

| Report Documentation Page  |                                    |  |   | Form Approved<br>OMB No. 0704-0188                        |                                 |
|--|------------------------------------|--|---|---|---------------------------------|
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| 1. REPORT DATE<br><b>06 AUG 2013</b>   |                                    | 2. REPORT TYPE<br><b>Briefing Charts</b> |   | 3. DATES COVERED<br><b>10-03-2013 to 25-07-2013</b>       |                                 |
| 4. TITLE AND SUBTITLE<br><b>UTILIZATION OF FAST RUNNING MODELS IN BURIED BLAST SIMULATIONS OF GROUND VEHICLES FOR SIGNIFICANT COMPUTATIONAL EFFICIENCY</b>   |                                    |  |   | 5a. CONTRACT NUMBER<br><b>W56HZV-08-C-0236</b>            |                                 |
|  |                                    |  |   | 5b. GRANT NUMBER  |                                 |
|  |                                    |  |   | 5c. PROGRAM ELEMENT NUMBER                                |                                 |
| 6. AUTHOR(S)<br><b>ravi thyagarajan</b>  |                                    |  |   | 5d. PROJECT NUMBER  |                                 |
|  |                                    |  |   | 5e. TASK NUMBER   |                                 |
|  |                                    |  |   | 5f. WORK UNIT NUMBER                                      |                                 |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br><b>Michigan Engineering Services, 2890 Carpтр Road # 1900, Ann Arbor, Mi, 48108</b>  |                                    |  |   | 8. PERFORMING ORGANIZATION REPORT NUMBER<br><b>#24071</b> |                                 |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br><b>U.S. Army TARDEC, 6501 East Eleven Mile Rd, Warren, Mi, 48397-5000</b>   |                                    |  |   | 10. SPONSOR/MONITOR'S ACRONYM(S)<br><b>TARDEC</b>         |                                 |
|  |                                    |  |   | 11. SPONSOR/MONITOR'S REPORT NUMBER(S)<br><b>#24071</b>   |                                 |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br><b>Approved for public release; distribution unlimited</b>  |                                    |  |   |   |                                 |
| 13. SUPPLEMENTARY NOTES<br><b>GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM (GVSETS), SET FOR AUG. 21-22, 2013</b>   |                                    |  |   |   |                                 |
| 14. ABSTRACT<br><b>Briefing Charts</b>   |                                    |  |   |   |                                 |
| 15. SUBJECT TERMS  |                                    |  |   |   |                                 |
| 16. SECURITY CLASSIFICATION OF:  |                                    |  | 17. LIMITATION OF ABSTRACT<br><b>Public Release</b> | 18. NUMBER OF PAGES<br><b>24</b>                          | 19a. NAME OF RESPONSIBLE PERSON |
| a. REPORT<br><b>unclassified</b>   | b. ABSTRACT<br><b>unclassified</b> | c. THIS PAGE<br><b>unclassified</b>      |   |   |                                 |

- Objectives
- Methods
  - Fast Running Models
  - Blast Event Simulation sysTem Methodology and Validation
- Case Study: Notional V-hull Structure
- Future Applications and Development

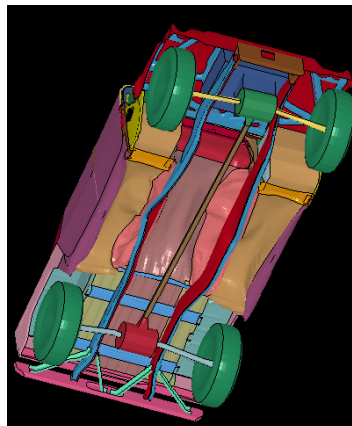
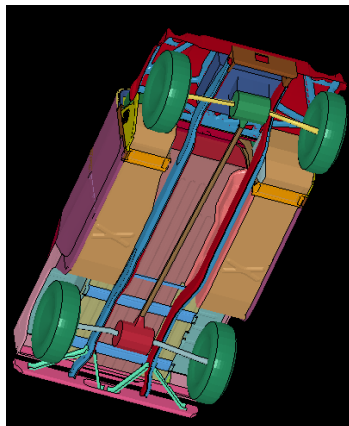
# Objectives

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- Survivability assessment requires thorough and systematic exploration of threat effects
- Current computational approaches require significant wall-clock time
- Fast Running Models (FRMs) are paired with the Blast Event Simulation sysTem (BEST) to accelerate analysis

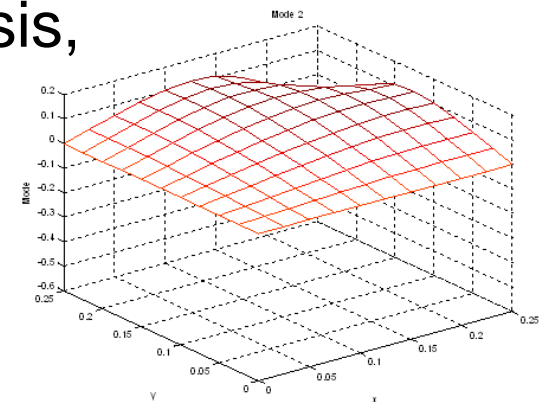
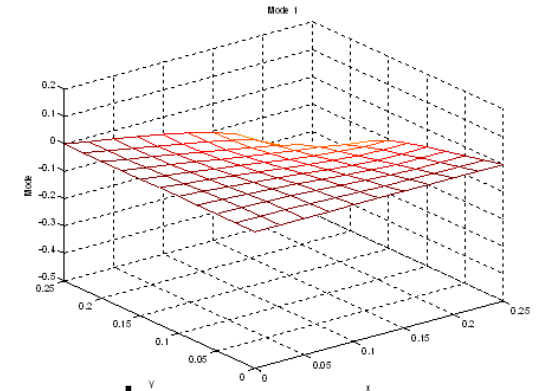


- FRMs comprise a reduced-order modeling approach that captures relevant physics governing relationships between input parameters and output effects
- Scenario parameters are input and time-series effects are output, much like complex multi-physics computational analysis
- Results are computed in seconds
- FRMs are a fusion of Principal Component Analysis (PCA) and Kriging

# Principal Component Analysis



- Reduce dimensionality of data set
- Distill blast loading histories into 'modal' information
- No linear limitations, PCA isolates fundamental characteristics that can be used as an expansion basis
- PCA used for nonlinear structural analysis, image processing, shock analysis, automotive crash analysis, molecular dynamics and more



# Principal Component Analysis



- Decompose response matrix  $X$ :

$$X = \begin{bmatrix} x_1(t_1) & \dots & x_1(t_k) \\ \vdots & \ddots & \vdots \\ x_J(t_1) & \dots & x_J(t_k) \end{bmatrix}$$



$$X = USV^T$$



$$X = [\Phi \quad \Phi_\tau] \begin{bmatrix} D & 0 \\ 0 & Z \end{bmatrix} \begin{bmatrix} \eta \\ \eta_\tau \end{bmatrix}$$

$$[U]$$

Each column is a “mode”

$$[\cancel{W}]$$

Only diagonal terms  
energy in each “mode”

$$[\cancel{V}]^T$$

Modal participation  
terms at each time  
step



- Time-dependent, reduced-order model:

$$[X(\gamma)] = [U(\gamma)][W(\gamma)][V(\gamma)]^T$$

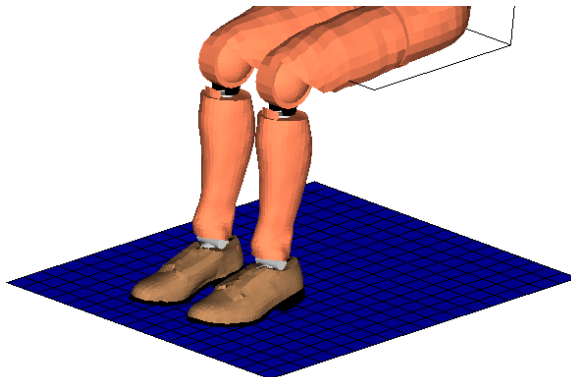
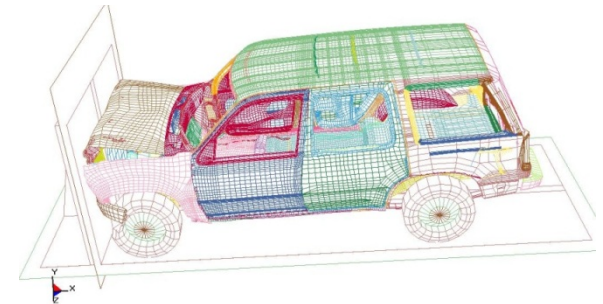
- Matrices generated by metamodels (Kriging):

$$[U(\gamma)], [W(\gamma)], [V(\gamma)]^T$$

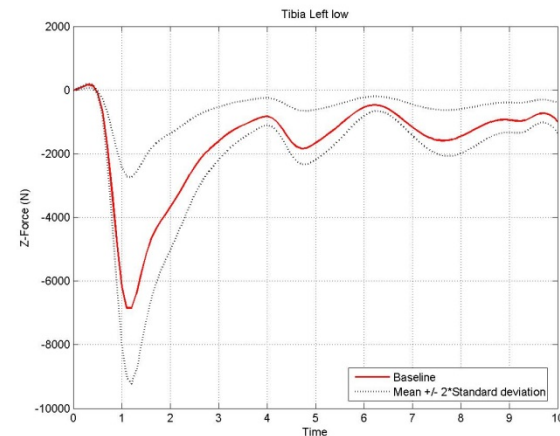
- Analyses are performed **at a limited number of training points**
- The values for [U], [W], [V] at the training points are used for developing the metamodels

# Previous Applications

- SAE-2005-01-2373 surface ship shock analysis
- SAE-2007-01-1744 automotive crash analysis
- SAE-2006-01-0762 uncertainty analysis for occupant safety under blast loads



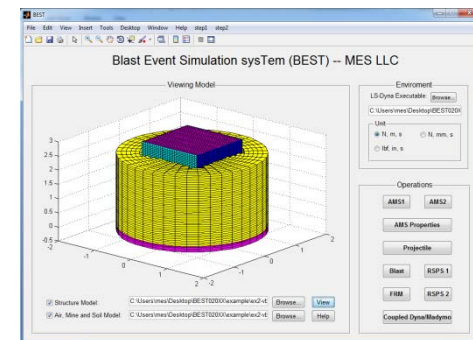
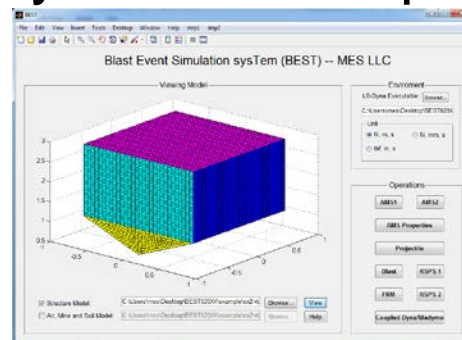
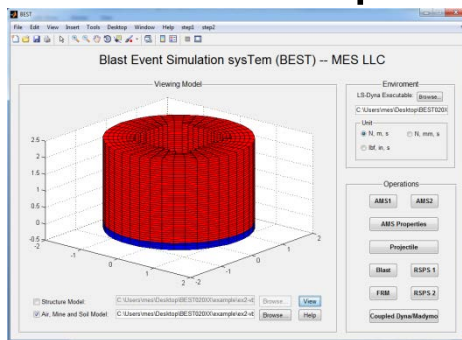
Time = 0.000000



# Blast Event Simulation sysTem

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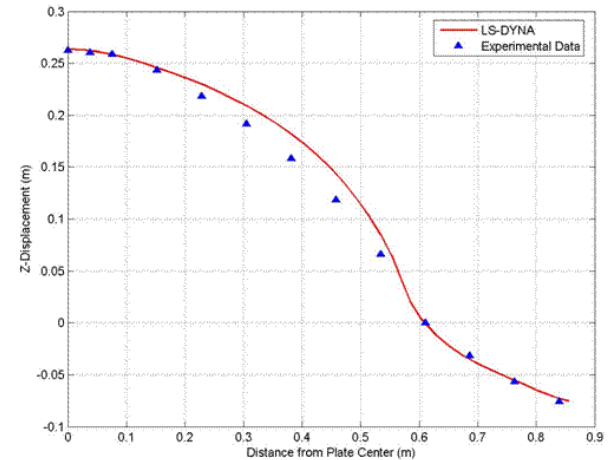
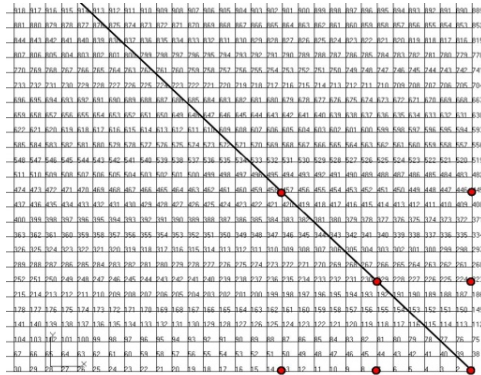
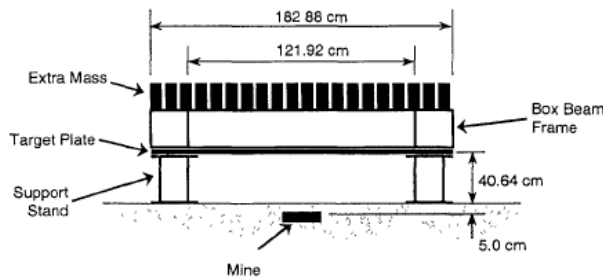
- Series of nested panels with buttons, input boxes, and drop down menus
- Organizes and automates mesh generation and simplifies simulation and post-processing
- Capable of defining and launching simulations and creating post-processing files through command line prompts and a suite of Fortran executables
- The FRM capability was developed within BEST



# Previous Validation

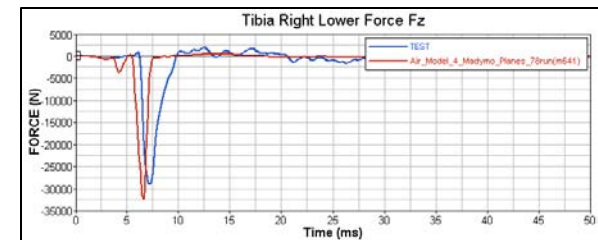
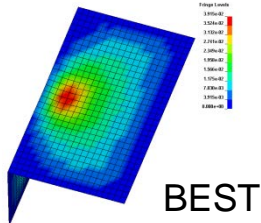
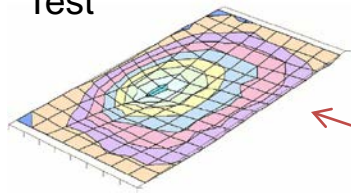


- SAE-2008-01-0781



- Vlahopoulos et al., Army Science 2010

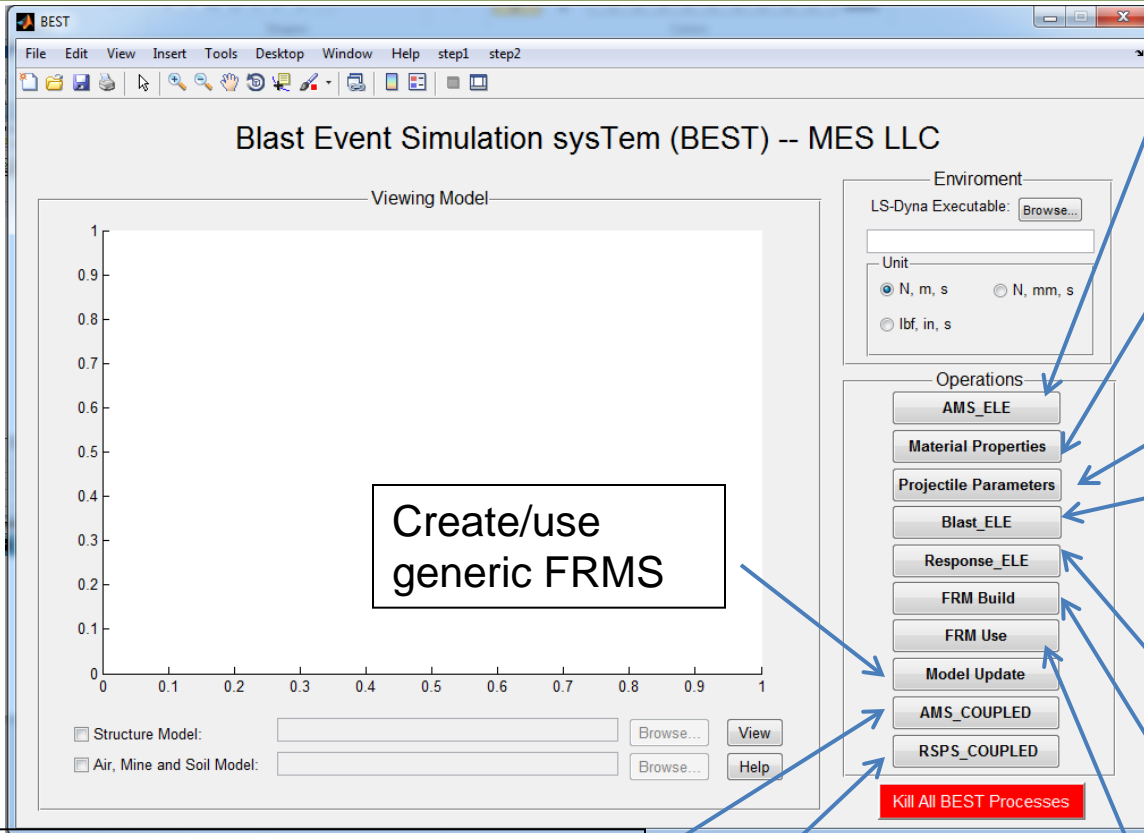
Test



# BEST Structure

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Generate air/soil/explosive model for 2-stage analysis

Material definition for soil, air, explosive. Varies due to moisture content.

Creation of projectiles as part of the explosive threat

LS-Dyna Eulerian analysis for 2-stage analysis

LS-Dyna Lagrangian analysis for 2-stage analysis

Create fast running models for underbody blast studies

Use fast running models for underbody blast studies

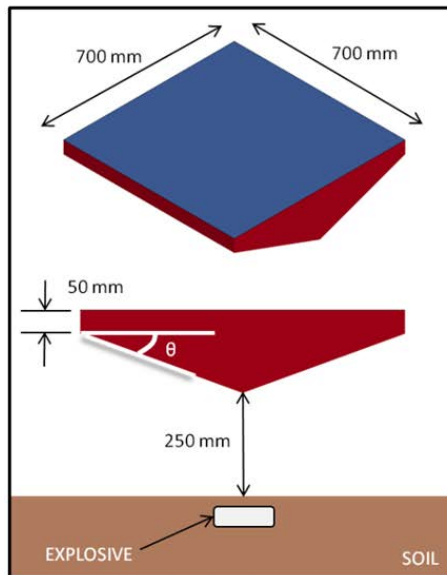
Create/use generic FRMS

Generate air/soil/explosive model for coupled analysis





LS-Dyna Lagrangian analysis for 2-stage analysis



- Emerging validation results for v-hull structure with varying geometry and charge size



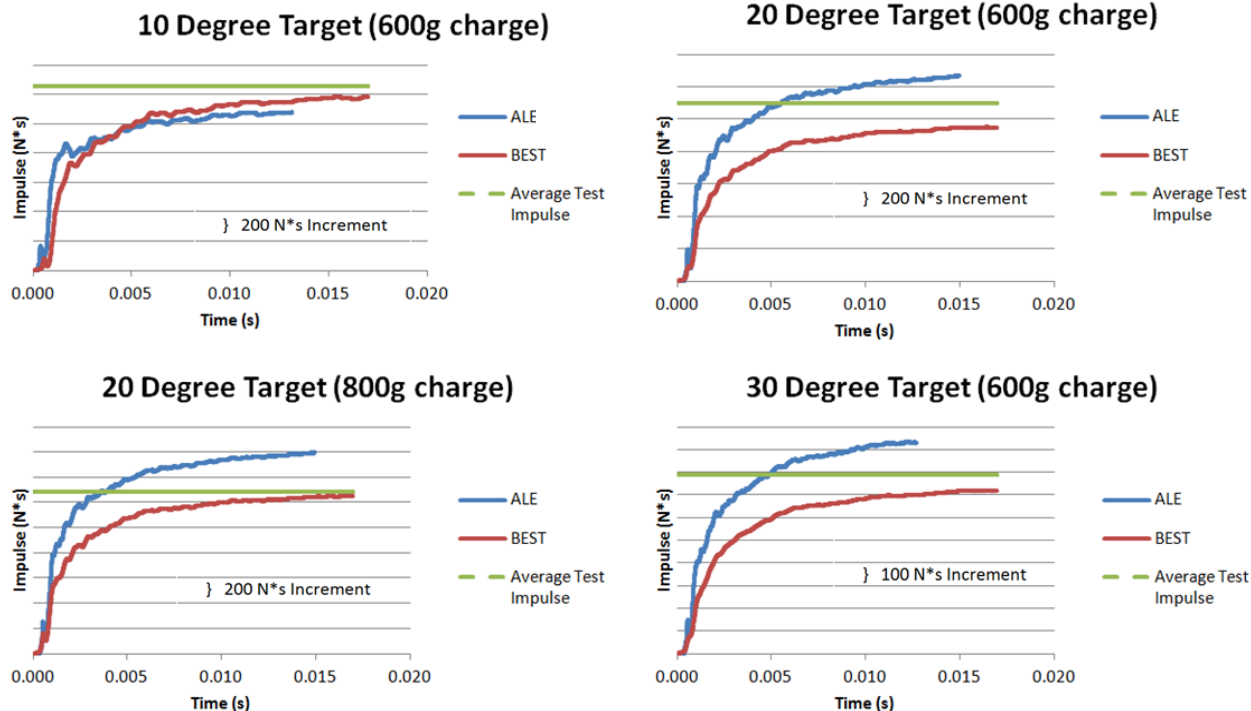
Test matrix:

| Geometry ( $\theta$ ) | 10 Degree  | 20 Degree   |   | 30 Degree   |             |
|-----------------------|--|---|---|---|-------------|
|                       |  |  |  |  |             |
| Charge                | 600 g  | 600 g   | 800 g   | 600 g   | Total Tests |
| Number of Tests       | 4  | 4   | 4   | 4   | 16          |



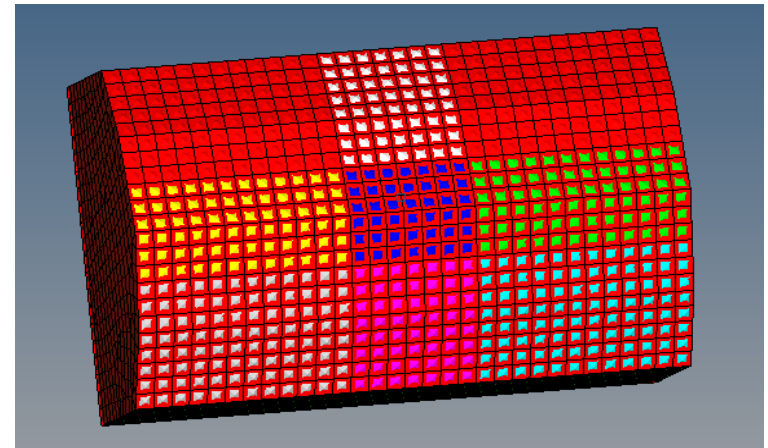
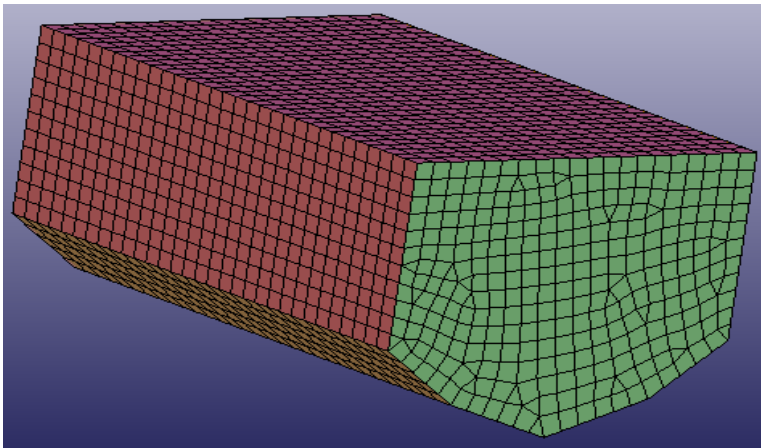
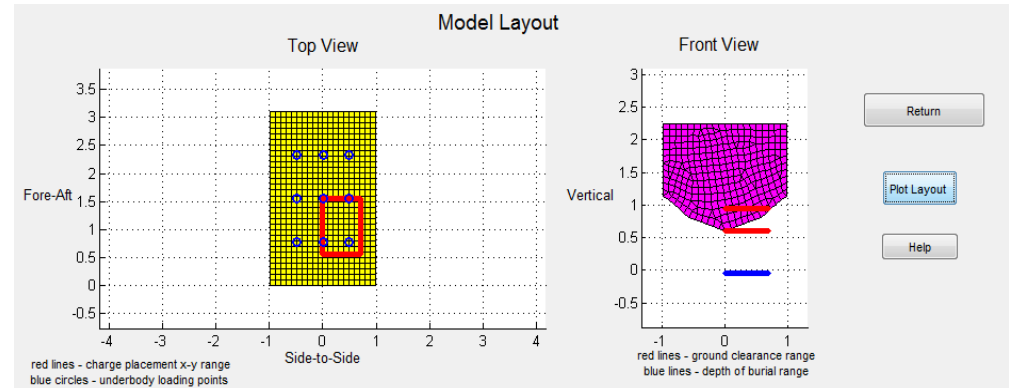


- Emerging correlation results with averaged experimental tests are at least as strong as fully-coupled ALE simulations



# FRM Terminology

- Input parameters
- Training points
- Loading points
- FRM applicable range



# BEST FRM Build Interface

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Build training point  
files and FRM

Specify parameter  
ranges

View loading point  
and FRM  
configuration

The screenshot displays the FRMBUILD software interface, which is used for building training point files and FRM (Finite Response Matrix) models. The interface is divided into several sections:

- FRM Build Section:** Contains a "Load pre\_FRM file" button with a file path "C:\Users\lmes\Des" and a "Browse" button. Below this, a note states: "\* Optional - only if FRM model previously exists".
- Parameter Ranges (Step 1):** A table for specifying parameter ranges for various parameters. The parameters and their ranges are:

| Parameter                 | Min | Max  |
|---------------------------|-----|------|
| Charge x coordinate range | -.5 | .5   |
| Charge y coordinate range | .5  | 2.65 |
| Ground clearance range    | 0   | .25  |
| Charge weight range       | 6   | 6    |
| Depth of Burial           | 0.1 | 0.2  |
- Build Section (Steps 2-7):** A series of steps for building the training point files and FRM model.
  - Step 2:** "Number of Training Points or Additional Points" with a text input field.
  - Step 3:** "AMS Parameters" with a button.
  - Step 4:** "Blast" with a button.
  - Step 5:** "Generate Training Point Input Files" with a button.
  - Step 6:** "Underbody Loading Point Grid" with a text input field, "x" and "y" axis labels, and a "Generate FRM" button.
  - Step 7:** "FRM Format" with a dropdown menu set to "TRUCK" and a "Generate FRM" button.
- Model Layout Section:** Contains two plots:
  - Top View:** A 2D plot showing the charge placement x-y range (red lines) and underbody loading points (blue circles). The x-axis ranges from -2 to 2, and the y-axis ranges from 0 to 3.
  - Front View:** A 3D plot showing the ground clearance range (red lines) and depth of burial range (blue lines). The x-axis ranges from -1 to 1, and the z-axis ranges from -0.5 to 2.

Legend for the plots:

- red lines - charge placement x-y range
- blue circles - underbody loading points
- red lines - ground clearance range
- blue lines - depth of burial range

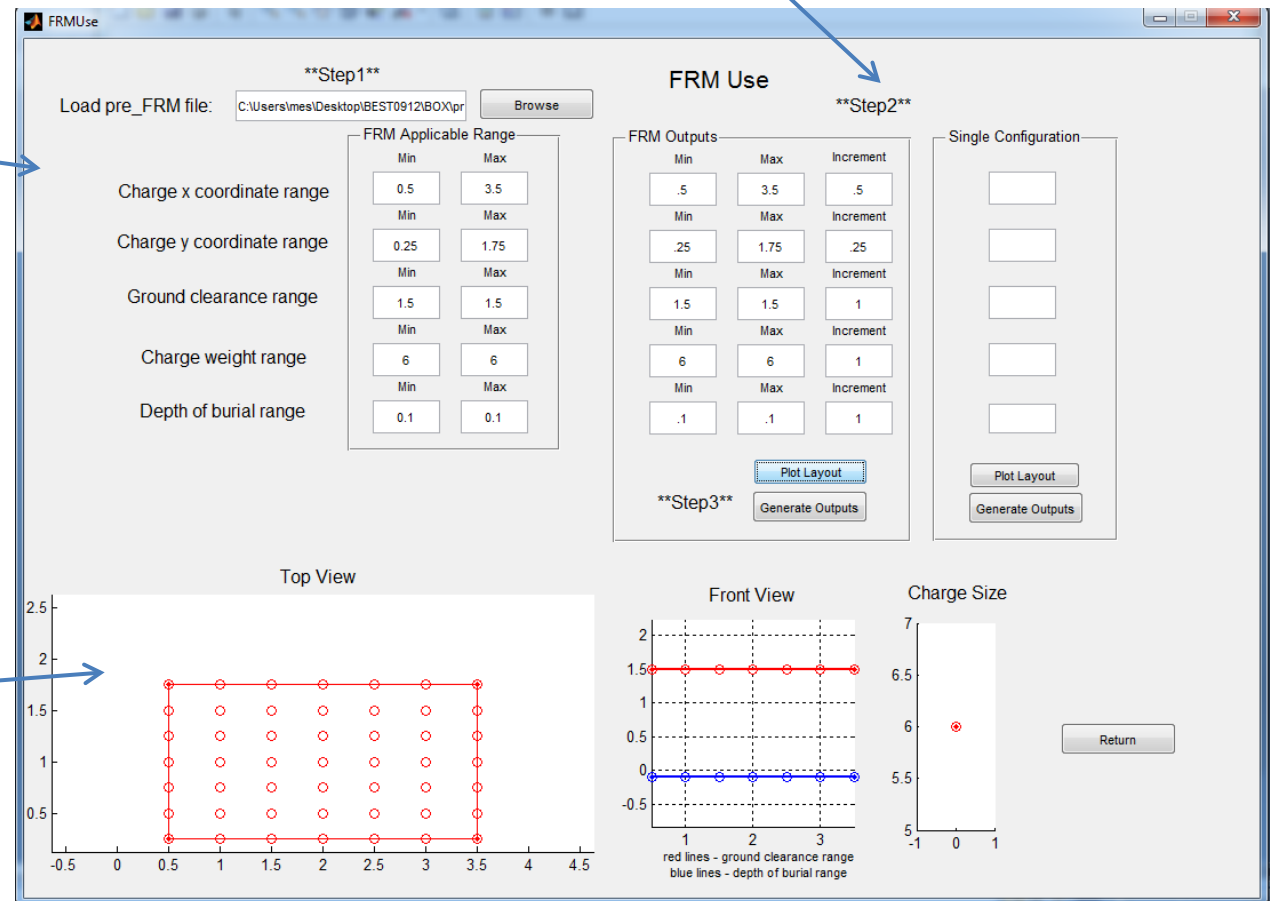
Buttons at the bottom right: "Return", "Plot Layout", and "Help".

# BEST FRM Use Interface

Desired mine/ vehicle configurations  
for response study

Automatically  
populated  
applicability ranges

Visual representation  
of FRM applicable  
ranges



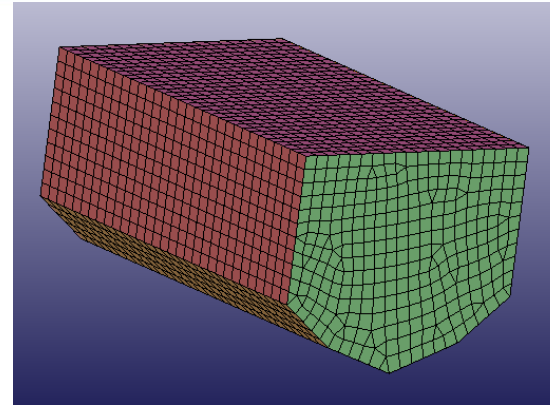
# Case Study - FRM

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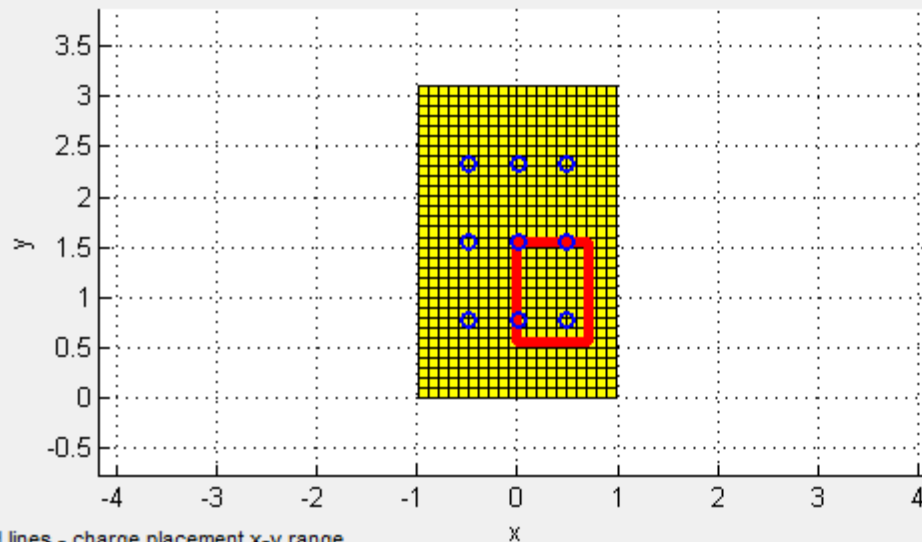
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- TARDEC V-hull
  - 20 Training Points
  - 9 Loading Points
  - 2 Evaluation Points

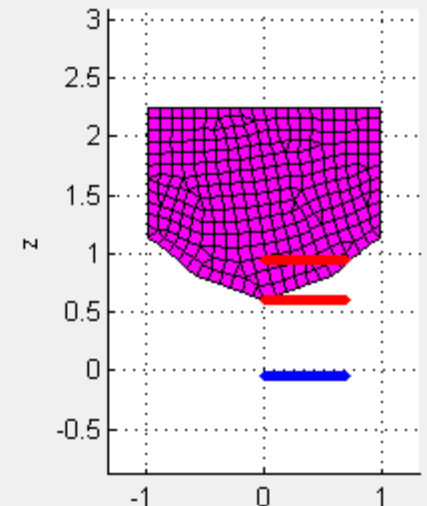


Top View



red lines - charge placement x-y range  
blue circles - underbody loading points

Front View



red lines - ground clearance range  
blue lines - depth of burial range

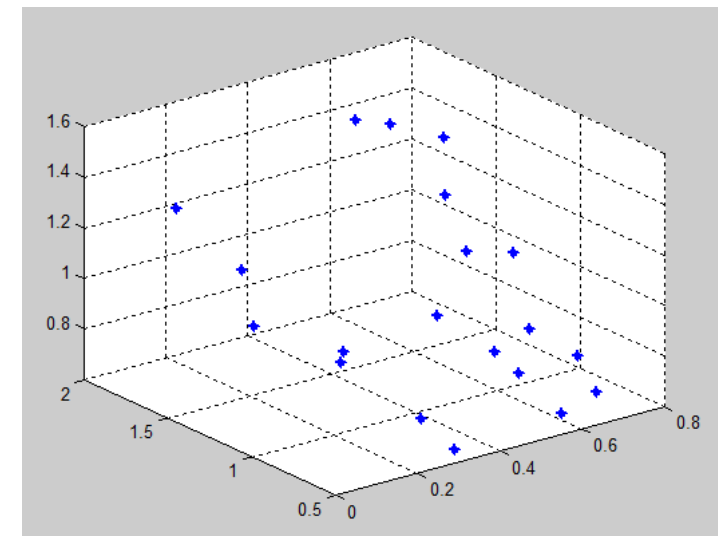
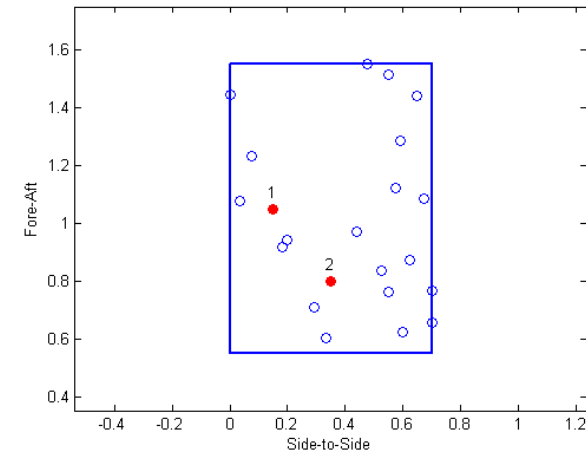
# Training Points

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- Training point ranges:
  - x location range: 0.7m
  - y location range: 1 m
  - ground clearance range: 0.65 m
  - depth of burial: 0.0508 m
  - charge size: Stanag Level 2
- Vehicle Dimensions:
  - width: 1.978
  - length: 3.1025
  - height: 1.6499



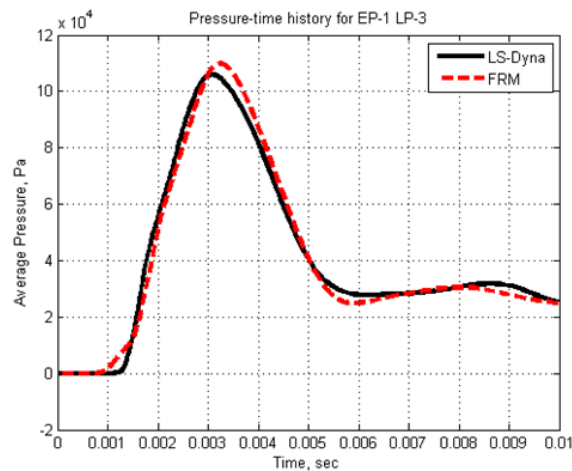
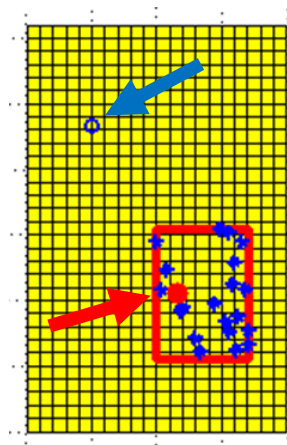
# FRM Results

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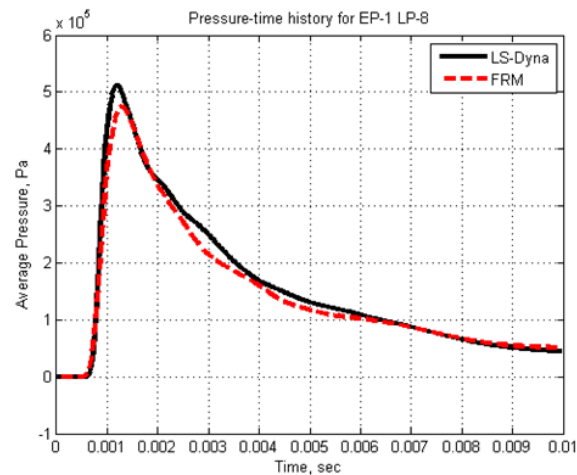
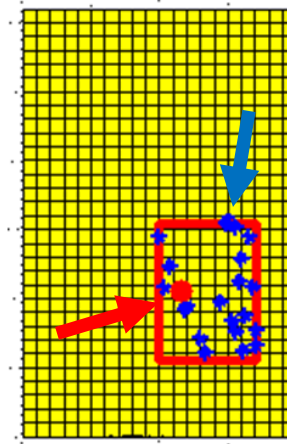
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- EP-1 LP-3:



- EP-1 LP-8:



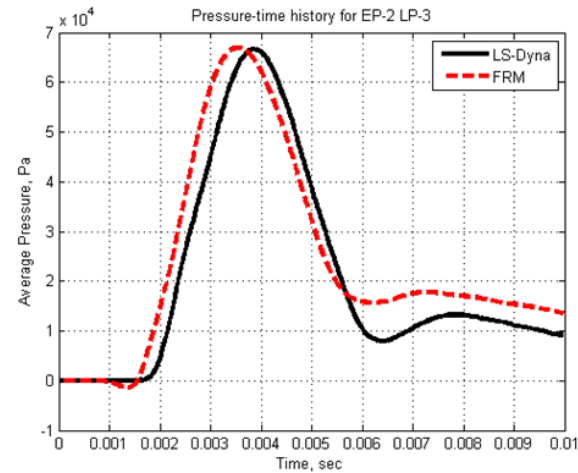
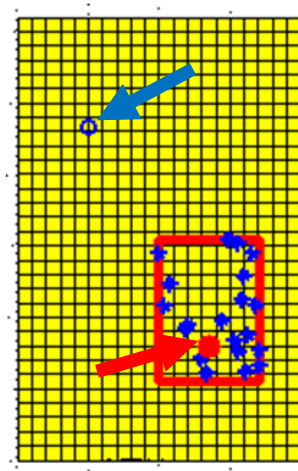
# FRM Results

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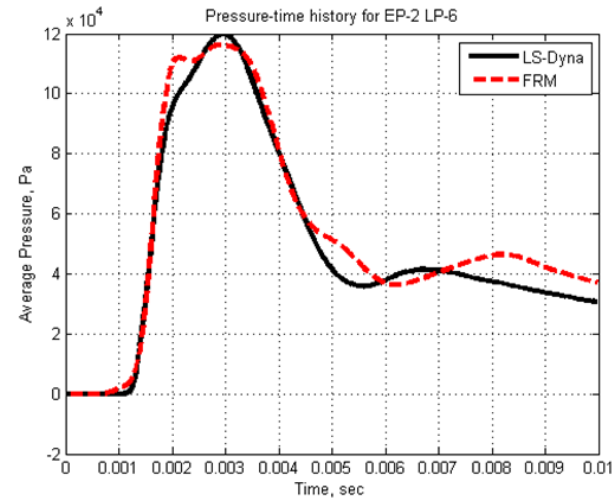
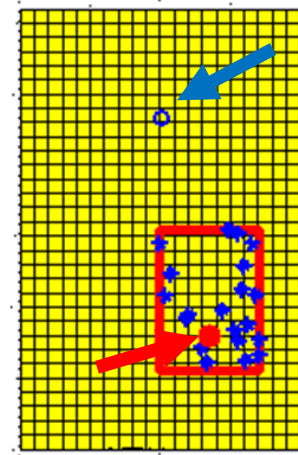
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- EP-2 LP-3



- EP-2 LP-6



# Case Study - Metamodel



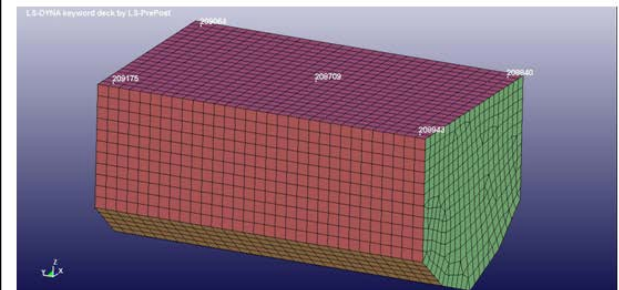
- FRMs can also be utilized to predict structural response
- Displacement of vehicle underbody tracked at all bottom nodes (630 total) to study **maximum displacement**
- Roof velocity tracked at 5 locations on roof to study **maximum average velocity**

Maximum Average Velocity  $\bar{V}_{Max}$  at One Surface of Hull: (Four Sides and Roof).

$$V_j(t_k) = \sqrt{V_{xj}^2(t_k) + V_{yj}^2(t_k) + V_{zj}^2(t_k)} \quad (\text{jth Node at time step } t_k)$$

$$\bar{V}(t_k) = \frac{\sqrt{\sum_{j=1}^N V_j^2(t_k)}}{N} \quad (N=5) \text{ at time step } t_k$$

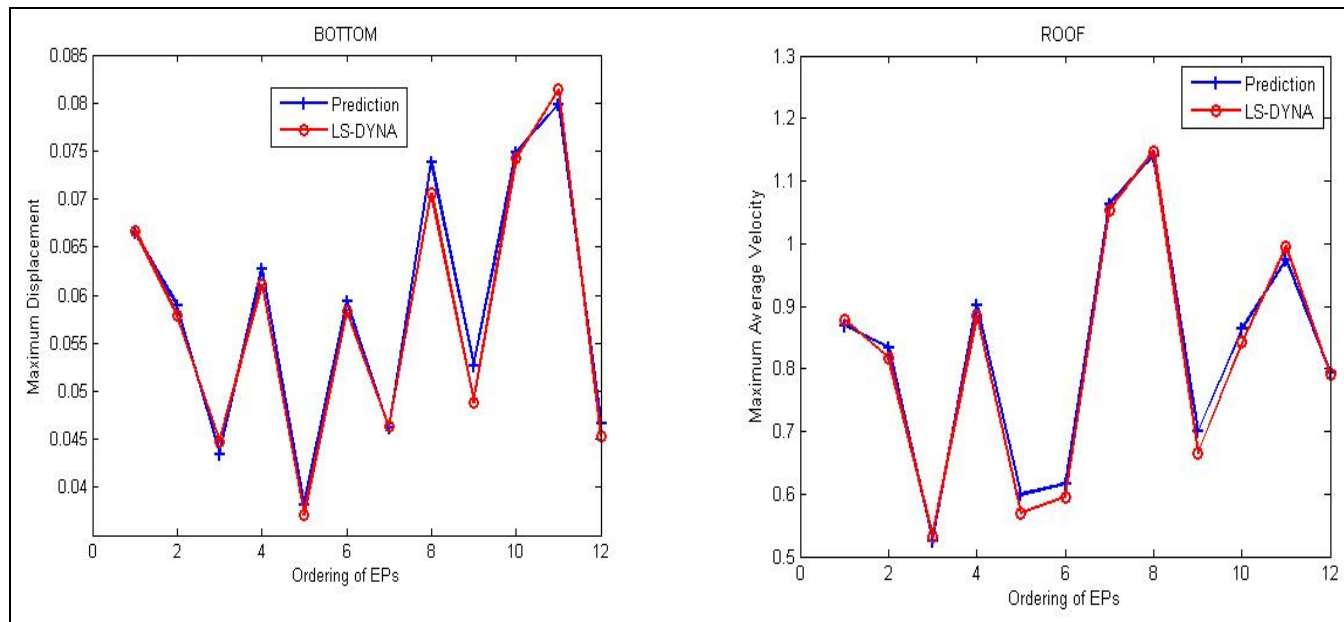
$$\bar{V}_{Max} = \text{Max}[\bar{V}(t_k)]$$



# Metamodel Results



- Both the maximum displacement and the maximum average velocity results correlate well with LS-DYNA simulation over 12 evaluation points





# Conclusions



- FRMs enable rapid evaluation of an entire matrix of vehicle/explosive configurations
- Both blast histories and structural responses can be modeled using FRMs
- The FRM capability has been incorporated in BEST to model any time-domain based physical event



- Two-step BEST approach justification:

